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SIMPLIFIED GAIN FLATTENING AND TAP DEVICE

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SIMPLIFIED GAIN FLATTENING AND TAP DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to and the benefit of U.S. Provisional Patent Application No. 60/430,479, filed December 2, 2002, entitled SIMPLIFIED GAIN FLATTENING AND TAP DEVICE FOR ADVANCED EDFA; which is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

The Field of the Invention

[0002] The invention generally relates to the field of fiber optic communications. More specifically, the invention relates to gain flattening filters for equalizing gain from an amplifier in an optical system.

The Relevant Technology

[0003] In the field of data transmission, one method of efficiently transporting data is through the use of fiber-optics. Digital data is propagated through a fiber-optic cable using light emitting diodes or lasers. Light signals allow for high transmission rates and high bandwidth capabilities. Also, light signals are resistant to electro-magnetic interferences that would otherwise interfere with electrical signals. Light signals are more secure because they do not allow portions of the signal to escape from the fiber-optic cable as can occur with electronic signals in wire-based systems. Light signals also can be conducted over greater distances without the signal loss typically associated with electronic signals on wire-based systems.

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[0004] While signal loss in a fiber-optic cable may be less than signal loss in wire-based systems, there is nonetheless some signal loss as light signals are transmitted over fiber-optic networks. Optical amplifiers are used to compensate for the signal loss. Two common optical amplifiers are Raman amplifiers and Erbium Doped Fiber Amplifiers (EDFAs). Both of these amplifiers use characteristics of doped fiber-optic cables to amplify light signals.

[0005] The amplifier pumps light onto the fiber-optic cable. The pumped light is at a different frequency than the light signal that is to be amplified. As the light signal and pumped light travel along the fiber-optic cable, energy from the pumped light is transferred to the light signal. Optical amplifiers use optical pumps, i.e. laser sources, to generate the pumped light.

[0006] In some fiber-optic applications, the light signals being transmitted may include different wavelengths of light. Each wavelength may be referred to as a channel. For example, the C-band might be used to transmit 40 different channels or wavelengths along the 1530 to 1562 nm bandwidth. In a variety of optical applications, it is desirable to amplify each channel with about the same optical gain. However, the optical gain of an optical gain medium, such as the doped fiber-optic cables, depends upon wavelength. In other words, optical amplifiers like Raman amplifiers and EDFAs, do not provide the same amount of optical gain to each channel in the light signals and some wavelength channels experience greater amplification than other channels. Consequently, a single gain medium does not usually function as a high gain medium having substantially uniform optical gain over an extended wavelength range.

[0007] Conventional approaches to providing uniform optical gain over an extended wavelength range typically have more components than desired, require significant

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numbers of optical interconnects resulting in insertion losses, and typically cost more than desired. Illustratively, EDFAs are widely used to amplify optical signals to compensate for transmission losses and insertion losses caused, for example by interconnection of components. The gain characteristics of EDFAs are a strong function of optical wavelength. Therefore, to achieve substantially uniform optical gain over an extended wavelength range, an additional gain equalization filter (GEF) he is needed in addition to the EDFA. In a single stage optical amplifier, GEFs are commonly placed after the final stage of the amplifier. For multi-stage amplifiers, GEFs are sometimes placed between amplifier stages. Each GEF introduces an additional component cost, component size, and requires appropriate packaging to permit it to be optically coupled to other components. Further, physically coupling components together results in some degree of insertion loss for each physical connection.

[0008] One type of GEF is based on a thin film having a wavelength sensitive transmission curve $G(f)$. Once an incoming beam $I(f)$ passes through the filter, the out-coming beam $O(f)$ can be described as:

$$O(f) = G(f) * I(f). \qquad (1).$$

[0009] The requirement of GEF transmission dynamics, or the amount of the variation in gain among the frequencies being equalized, depends on the application. In some cases, a wide dynamic range (e.g., more than 10 dB) is required to ensure that the game of each channel is equalized. This can make the GEF filter difficult to make and expensive.

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BRIEF SUMMARY OF THE INVENTION

[0010] One embodiment of the invention includes a gain flattening filter (GFF) for use in fiber-optic communications. The GFF includes a substrate. The substrate has a GFF film on a first surface of the substrate. A high reflection (HR) film is disposed on a second surface of the substrate. The HR film is arranged to receive a light signal from the GFF film and to reflect a least a portion of a light signal back through the GFF film.

[0011] Another embodiment of the invention includes a method of manufacturing a fiber-optic component that includes a gain flattening filter. The method includes forming a GFF film on a first surface of an optical substrate. The method further includes forming an HR film on a second surface of the optical substrate. Forming an HR film on a second surface includes arranging the HR film so the HR film is configured to receive light that is passed through the GFF and to reflect a least a portion of the light back to the GFF film.

[0012] Yet another embodiment of the invention includes a method for equalizing non-uniform gain in an optical signal. The method includes passing a light signal through a GFF film. The method further includes passing the light signal from the GFF film through a substrate to an HR film. The method further includes reflecting the light signal at the HR film back through the GFF film. The method further includes directing the reflected light signal into an output port.

[0013] Advantageously, embodiments of the invention allow for using a GFF film with reduced performance characteristics such as reduced dynamic range. A single GFF film with reduced performance characteristics may be used because by passing a light signal through the GFF film multiple times allows the effect of the GFF film to be multiplied.

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[0014] Embodiments of the invention may also allow for the implementation of a combination GFF/tap. By using an HR film that allows a portion of an optical signal to pass through the HR film, an optical signal can be effectively tapped for analyzing the optical signal or for extracting optical channels comprised of the optical signal.

[0015] These and other advantages and features of the present invention will become more fully apparent from the following description and appended claims, or may be learned by the practice of the invention as set forth hereinafter.

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BRIEF DESCRIPTION OF THE DRAWINGS

[0016] To further clarify the above and other advantages and features of the present invention, a more particular description of the invention will be rendered by reference to specific embodiments thereof which are illustrated in the appended drawings. It is appreciated that these drawings depict only typical embodiments of the invention and are therefore not to be considered limiting of its scope. The invention will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

[0017] Figure 1A illustrates one embodiment of a GFF;

[0018] Figure 1B illustrates one embodiment of a GFF with a tap function with tapped light being directed into a tap port; and

[0019] Figure 1C illustrates one embodiment of a GFF with a tap function with tapped light being directed into a photodiode.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0020] Some embodiments of the present invention implement a gain flattening filter (GFF) that equalizes, or substantially equalizes gain across a bandwidth of frequencies. This may be useful to compensate for unequal gain that is caused by Erbium Doped Fiber Amplifiers (EDFAs), Raman amplifiers and the like. The GFF uses an optical film filter on one side of a substrate. A high reflection (HR) film is used on the other side of the substrate. The GFF functions by an optical signal being passed through the optical film filter, reflected off the HR film and passed through the optical film filter again, effectively multiplying the effectiveness of the optical film filter so as to reduce the complexity and cost of the GFF film. In one embodiment of the invention, the GFF also incorporates an optical tap for either extracting a single wavelength of the optical signal, or for extracting a portion of the power of the optical signal. This may be implemented by using an HR film that allows a single wavelength or group of wavelengths to pass through the HR film.

[0021] Figure 1A illustrates one embodiment of a GFF 102 disposed in a typical operating environment. The GFF 102 is optically coupled to an input port 104 and an output port 106. In one embodiment of the invention, the input port 104 may be a portion of an EDFA or other amplifier device. In another embodiment of the invention, the GFF 102 may be designed to pre-compensate for an optical amplifier located at, or after the output port 106. In either case, the GFF is configured to attenuate gain at certain wavelengths so as to cause the gain across all wavelengths to be substantially uniform.

[0022] The GFF 102 includes a substrate 110. The substrate 110 is optically transparent for wavelengths of light used with the GFF 102 in this embodiment. One

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surface 111 of the substrate 110 is coated with a GFF film 112. The GFF film 112 is designed to equalize gain by attenuating certain wavelengths of light. An opposing surface 113 of the substrate 110 is coated with an HR film 114. The light beam coming from the input port is collimated or focused by a first lens 116. The collimated beam passes through the GFF film 112, the substrate 110 and is reflected by the HR film 114. This reflected light once again passes through the substrate 110, the GFF film 112 and is launched by the first lens 116 into the output port 106. The beam launched into the output port 106 can be described as:

$$O(f) = I(f) * G(f) * HR(f) * G'(f) \qquad (2).$$

[0023] In equation (2), $O(f)$ is the beam launched into the output port as a function of frequency. $I(f)$ describes the beam from the input port 104 as a function of frequency. $G(f)$ is the frequency response of the GFF film 112 for light traveling through the GFF film 112 towards the substrate 110. $HR(f)$ is the frequency response of the HR film 114 as is relates to light that is reflected off of the HR film 114. G'(f) is the frequency response of the GFF film 112 for light traveling through the GFF film 112 away from the substrate 110. By using an HR film 114, the effect of the GFF film 112 is the combined frequency response of $G(f)*G'(f)$. This allows for the use of GFF films with narrower dynamic ranges to achieve an adequate equalizing effect.

[0024] In another embodiment shown in Figure 1B, the HR film 114 is configured to allow one or more wavelengths of light or a percentage of one or more wavelengths of light to pass through the HR film to a tap port 108. Light passing through the tap port 108 is focused or collimated by a second lens 120 such that the light is launched into the tap port 108. In this way, a tap and GFF can be implemented in a simple cost effective way. The signal $T(f)$ output to the tap port 108 can be described as:

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$T(f) = I(f)*G(f)*[1\text{-}HR(f)]$.

The signal launched into the tap port 108 may be used for network analysis such as for example when the HR film 114 is designed to allow a percentage of one or more wavelengths of light to pass through. Alternatively, the GFF 102 may be used as the drop portion of an optical add drop module for extracting a particular wavelength of light that includes data in a channel needed by a device in an optical network.

[0025] Another embodiment is illustrated in Figure 1C. Figure 1C shows a photodiode 122 arranged to receive an optical signal passed through the HR film 114. Using a photodiode 122 allows the GFF 102 to be implemented in an optical transceiver or other optical component that has a need to convert an optical signal to an electronic signal.

[0026] Advantageously, in one embodiment of the invention, the GFF film requirements are relaxed as compared to other GFF filters. As discussed earlier, some optical amplifier designs require a GFF filter with a dynamic range of up to 10 dB. This can make the GFF difficult to fabricate and expensive. By reflecting the input beam, the beam passes through the GFF filter 112 twice. In an embodiment of the invention where the frequency response $G(f)$ of the GFF filter for light traveling towards the substrate 110 is the same as the frequency response $G'(f)$ for light traveling away from the substrate 110, the GFF filter would only need to have a 5dB dynamic range. The difficulty of fabricating and the cost of the filter are therefore reduced.

[0027] Other configurations may also be implemented within the scope of the embodiments of the present invention. For example, referring to Figure 1D, a GFF filter 102 includes the HR film 114 disposed on the optical substrate 110. The GFF film 112

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is disposed on the HR film 114. This configuration allows the GFF film to be used twice to flatten gain as light signals are reflected off of the HR film 114.

[0028] Figure 1E illustrates an embodiment where multiple GFF films with lower dynamic ranges may be used. A first GFF. film 112a is disposed on the optical substrate 110. The first GFF film 112a flattens gain as light passes through the first GFF film. An HR film 114 is positioned so as to reflect a light signal from the first GFF film 112a to a second GFF film 112b. The second GFF film 112b further flattens gain. Using this configuration, although two GFF films are used, the GFF films may have a lower dynamic range. The GFF films may have similar or different optical characteristics within the scope of various embodiments of the invention.

[0029] The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

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